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N87-16762 21P.

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1986

NASA/ASEE SUMMER FACULTY FELLOWSHIP PROGRAM

MARSHALL SPACE FLIGHT CENTER
THE UNIVERSITY OF ALABAMA

STRATIFIED PROCESSES TO ANALYZE SSME PARTS AND SUBSYSTEMS USING WEIBULL METHODOLOGY

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Date: August 15, 1986

Contract No.: NGT-01-002-099
The University of Alabama

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ABSTRACT

Due to the various parts found in a Space Shuttle Main Engine (SSME), analyzation of every part is not feasible or needed. Based on previous mathematical modeling experience of high velocity cryogenic equipment, Gray determined the environmental traits of location of the part, temperature range, fluid velocity, pressure range, and elevation variation of fluid flow as being significant factors. Deborah Leath (engineer) developed six parts categories. The part categories are: (1) fuel turbomachinery, (2) oxidizer, (3) combustion devices, (4) valves, (5) ducts, and (6) lines. Due to a suspicion by Gray, that superficial failure modes exist, six status codes were developed in consultation with Leath. The codes are: (1) part is in service presently, (2) part is out-of-service due to its own failure, (3) part is out-of-service due to engine (or some other part failure), (4) part is out-of-service because it's retired/obsolete (time related), (5) never fired-scrapped due to own problem or part is store, and (6) part is out-of-service for repair. Due to maintenance policies, Gray asserted that status code 3 needed two subcodes: (1) service decision and (2) discarded to have assess to needed repairs. Gray assigned status code 4 with the subcodes: (1) due to age and (2) due to new design. Based on a problem found with developing models using status code 6, Gray decided that repair should have the 2 subcodes of: (1) problem and (2) design alteration. Gray suggested that to properly model failure behavior of SSME parts that: (1) significant factors contributing to failure must be examined, (2) relative precision based on real life data must be examined, and (3) alternative definitions of failure must be initialized by the engineers.

ACKNOWLEDGMENTS

I wish to thank engineers Johnathan Campbell, Deborah Leath, and J.P. Jones for their help in securing sufficient data. An extra special thanks goes to Deborah Leath for spending many extra hours researching and categorizing parts data, while providing input to efforts to categorize the subsystems and their parts of the Space Shuttle Main Engine. A special tanks to Mario Reinfort for providing resources. Thanks to Geri Davis for typing this report.

INTRODUCTION

As a continuing effort to determine how Weibull analysis methodology can be applied to Space Shuttle Main Engine (SSME), a method to stratify parts in SSME was developed. The major problem with using Weibull methodology is that frequently a beta value of one is obtained on most SSME parts. The researcher Gray determined that due to the real life performance of the SSME, factors which mathematically alter the value of beta were present. Gray also decided that the safety margin in at least two ways provided the reason for continuous multiple failure modes being implied by the beta value of one. Hence, Gray decided to generate models to make an effort to analyze the problem.

PROBLEM STATEMENT

To what extent can the SSME parts reliability be analyzed statistically by using selected SSME parts based on stratification? Is stratification a feasible effort, along with using Weibull methodology?

PROCEDURE

During the first week of research activities, Deborah Leath (engineer) and Lou Gray (investigator) met frequently to develop strategies to select parts for analysis. As a result of these activities, the following categories of major parts were determined by Leath: (1) fuel turbomachinery, (2) oxidizer, (3) combustion device, (4) valves, (5) ducts, and (6) lines. Based on previous mathematical modeling experience of high velocity cryogenic equipment, Gray determined the environmental traits of: (1) location of the part, (2) temperature range, (3) fluid velocity, (4) pressure range, and (5) elevation variation of fluid flow as being significant factors (see figure 1).

Leath and Gray together develop a strategic and rational to categorize engine parts by a status code (see figure 2). The codes are:

1. Part is in service presently. <u>Rationale:</u> Pertinent current data.

EP12503

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HYPOTHETICAL CASE

CATEGORY	TYPE	LOCATION	PRESSURE
OXIDIZER	BLEED VALVE	NEAR UPPER PORTION	HIGH

FIGURE 1

EP12527

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CHART NO. 20	STRATIFICATION OF SSME PARTS	DATE: AUGUST 8, 1986

CODES

1. PART IN SERVICE
2. PART HAS OWN FAILURE
3. PART OUT OF SERVICE
   - 11 SERVICE DECISION
   - 12 DISCARDED TO HAVE ASSESS TO NEEDED REPAIRS
4. RETIRED
   - 21 DUE TO AGE
   - 22 DUE TO NEW DESIGN
5. NEVER FIRED - SCRAPPED
6. REPAIR
   - 31 PROBLEM
   - 32 DESIGN ALTERATION

FIGURE 2

2. Part is out-of-service due to its own failure. Rationale: Failed to perform as designed.

3. Part is out-of-service due to engine (or some other part failure). Rationale: Maintenance policy sometimes require the discarding of parts even though the parts have not failed.

4. Part is out-of-service because it's retired or obsolete (time related). Rationale: Aging can result in inefficiency of the part. New designs may replace older parts.

5. Part is never-fired scrapped or part is in storage. Rationale: Scraping is a quality control problem. Storage is possible occurrence.

6. Part is out-of-service due to repair. Rational: Problem may develop. Design alterations may occur.

The routine way of programming using only status code 2 as a failure and codes 3, 4, and 6 as suspension was done. The parts examined for this study are: (1) nozzles, (2) powerheads, (3) main combustion chamber (MCC), and (4) main injector (MI). The models developed for this study are shown in figure 3. Note that code 5 is not used and code 6 does not apply to MCC due to nickel coating design alteration.

EP12528

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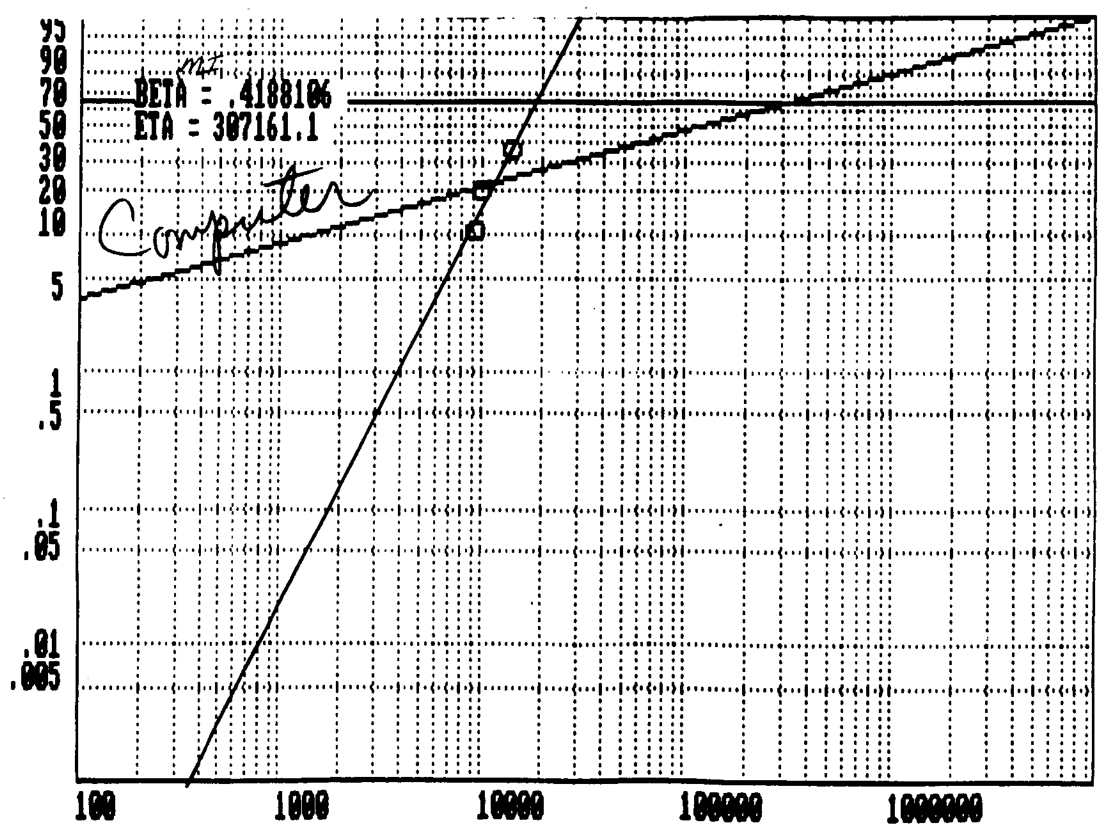
CHART NO.	STRATIFICATION OF SSME PARTS	DATE AUGUST 8, 1986

EXPERIMENTAL MODELS

MODEL NUMBER	FAILURE CODES	SUSPENSION CODES
1	2, 3, 4	NONE
2	2, 4	NONE
3	2, 4, 6*	NONE
4	2, 4, 6*	3
5	2, 6*	4, 3
6 (MCC ONLY)	2, 4	3

FIGURE 3

*DUE TO NICKLE COATING ON MCC NOT USED



GENERAL MODEL FAILURE CODE: 2 SUSPENSION CODE: 3,4,6 N = 43 SUSPENSION = 39

FIGURE 4

RESULTS

The general routine of using only obsolete failure with suspensions did not produce data compatible to actual life data of SSME parts. Also, the computer graph for MI reflects inability to recognize extreme points (see figure 4). The maximum likelihood graph is not as easily influenced by the presence of an extreme point since it is totally derived by computations (see figure 5).

Main Injector (MI)

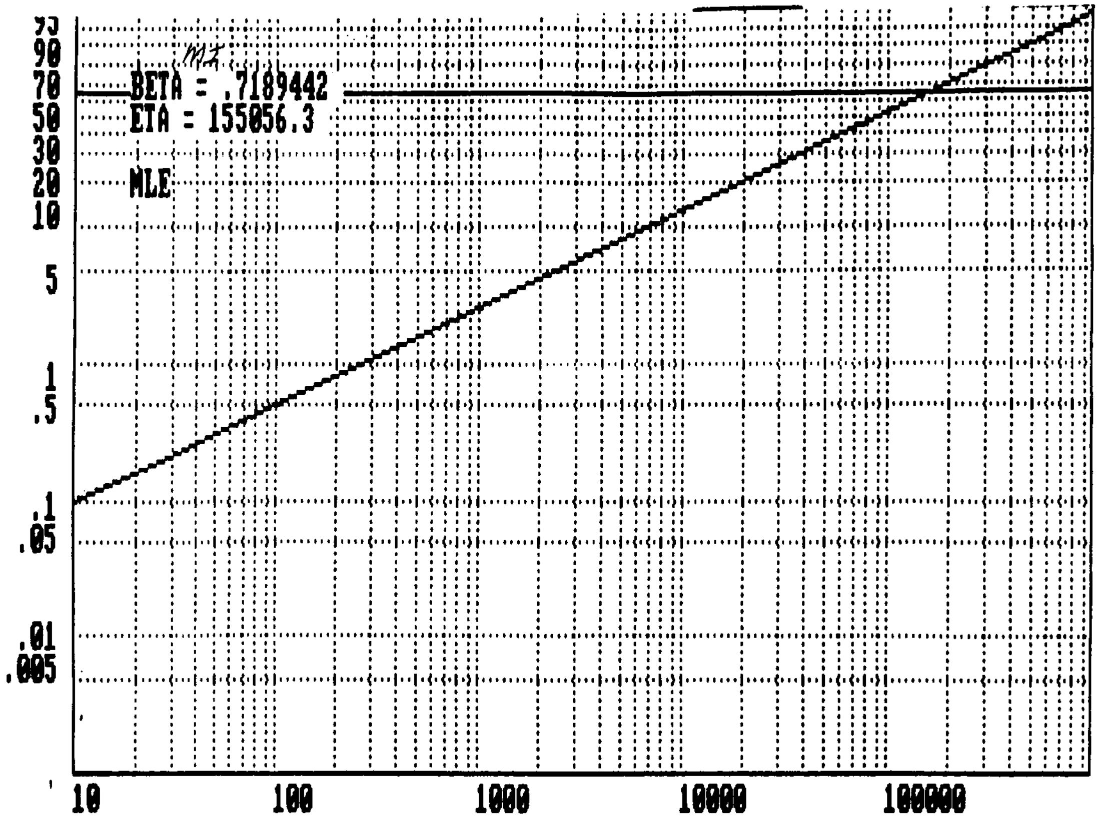
Model 1 for MI resulted in a beta considerably smaller than 1 (Beta = 0.6218367). Yet, multiple failure modes may exist (see figure 6). The graph done by the computer appears not to represent a failure mode for model 1. The graph is of a centroid nature. Model 2 for the MI has a distinct failure mode (see figure 7) yet, the actual performance of the SSME part is not defined at the B.01 of B.05 life level. Model 3 for the MI is the same as model 2. Model 4 also generate a distinct single failure mode (see figure 8) which is not compatible with available performance data. For the MI, model 5 generates a beta of 3.828949 and has a reasonable B.01 and B.05 life (see figure 9).

Nozzle

Models 1 and 2 both produced multiple failure modes since the betas were 1.12763 and 0.9750785, respectively (see figures 10 and 11). Model 2 and model 3 are the same due to the data. Multiple failure modes are still evident for the nozzle (see figure 12). The beta of 0.9189662 and the additional graphing by eye indicates more than one failure mode (see figure 13) for model 5. The B.01 life and B.05 life indicated by model 5 on the computer is totally irrational for B.01 occurs before firing.

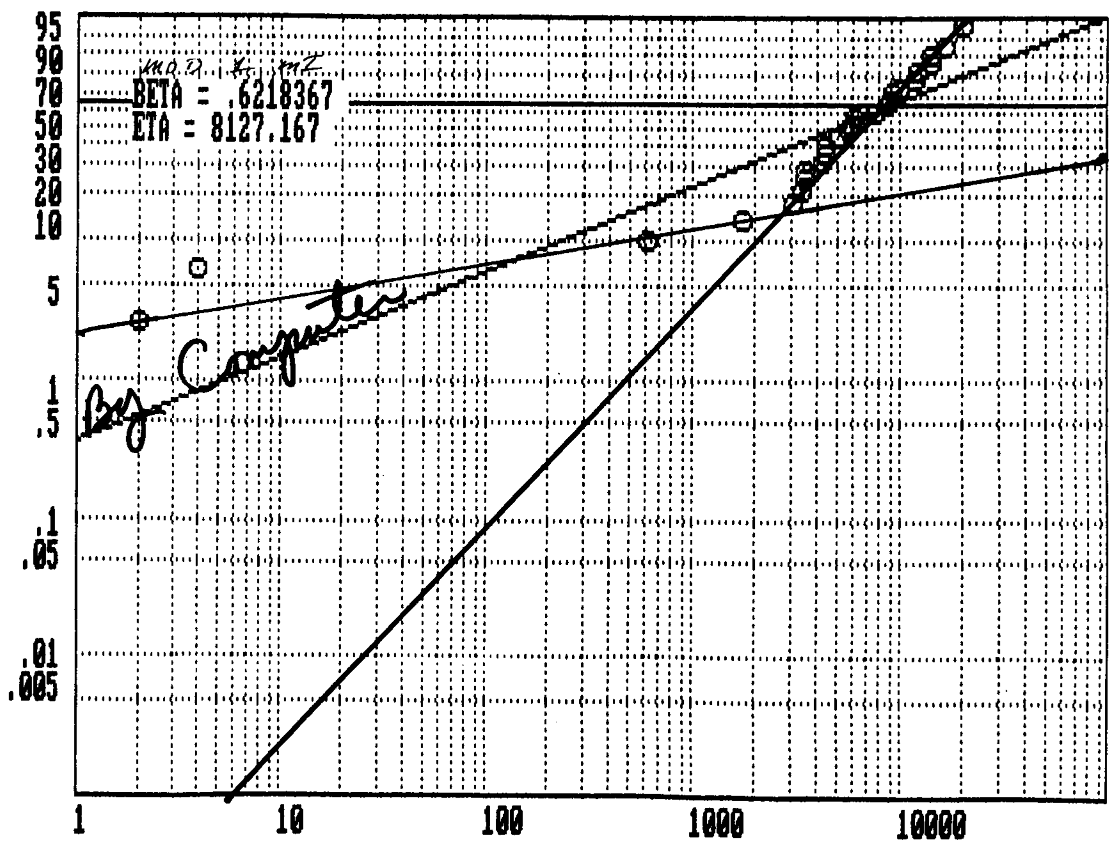
Powerhead

Model 1 for the powerhead generates a beta of 1.354549 which reflects possibly no multiple failure modes. Yet, by eye a few could exist (see figure 14). Model 2 has a beta value which does not reflect random failure; however, the B.01 and B.05 life is not realistic for actual data. By eye, several failure modes could exist (see figure 15). Notice the lines by eye show slopes of failure beyond 1200 seconds which is more compatable to real data. Again, the computer graph fails to reflect multiple



N = 43

FIGURE 5



FAILURE CODES: 2,3,4 SUSPENSION: NONE N=26 FIGURE 6

MODEL 1, MI

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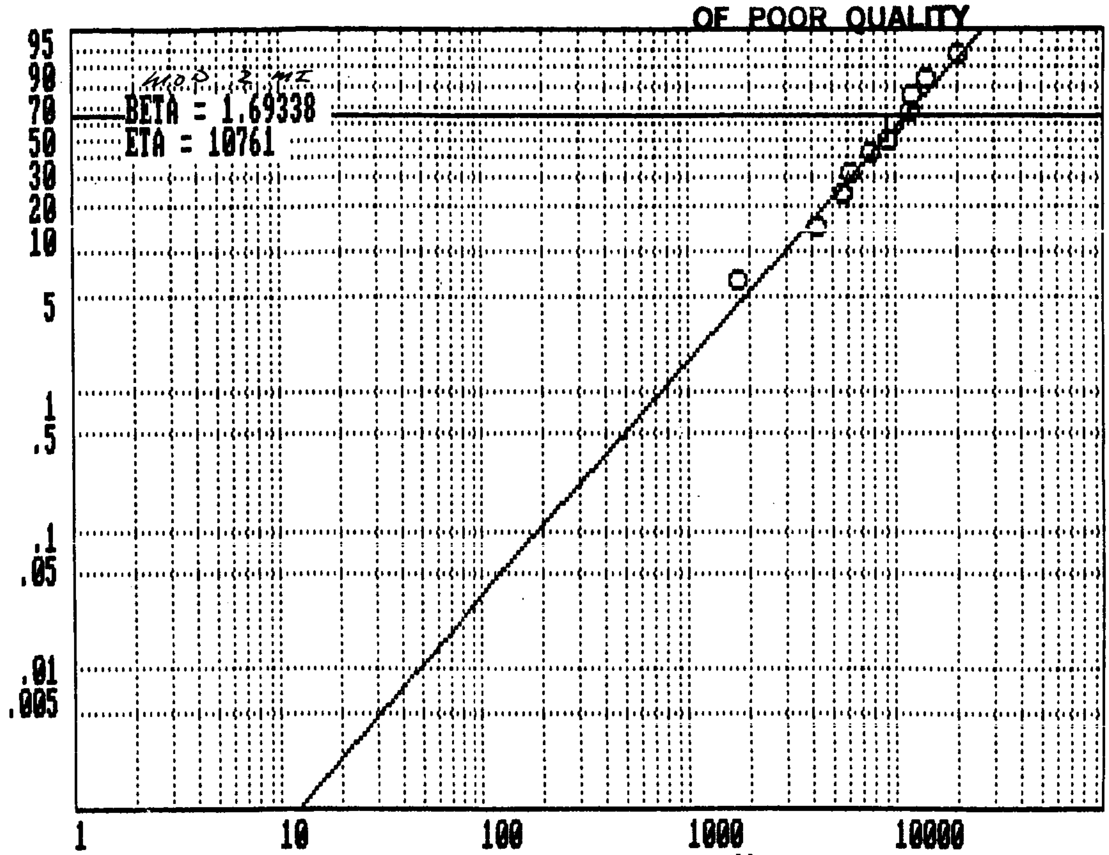
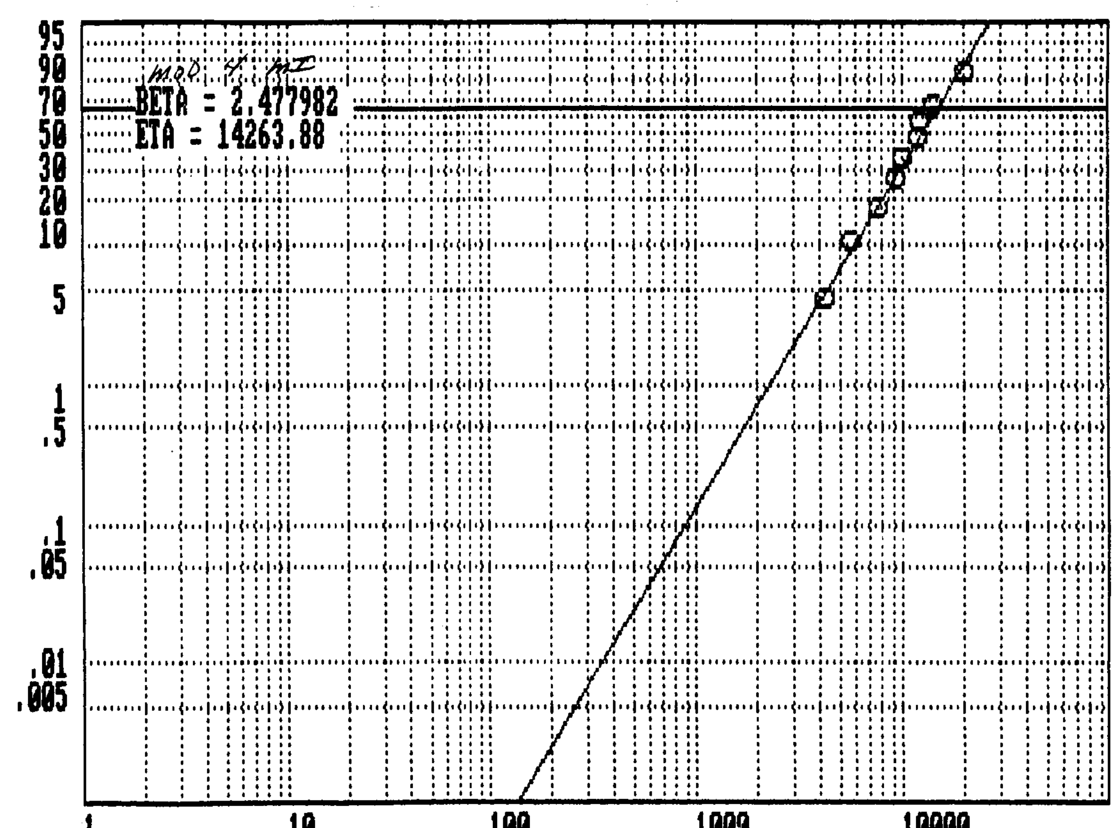
OF POOR QUALITY



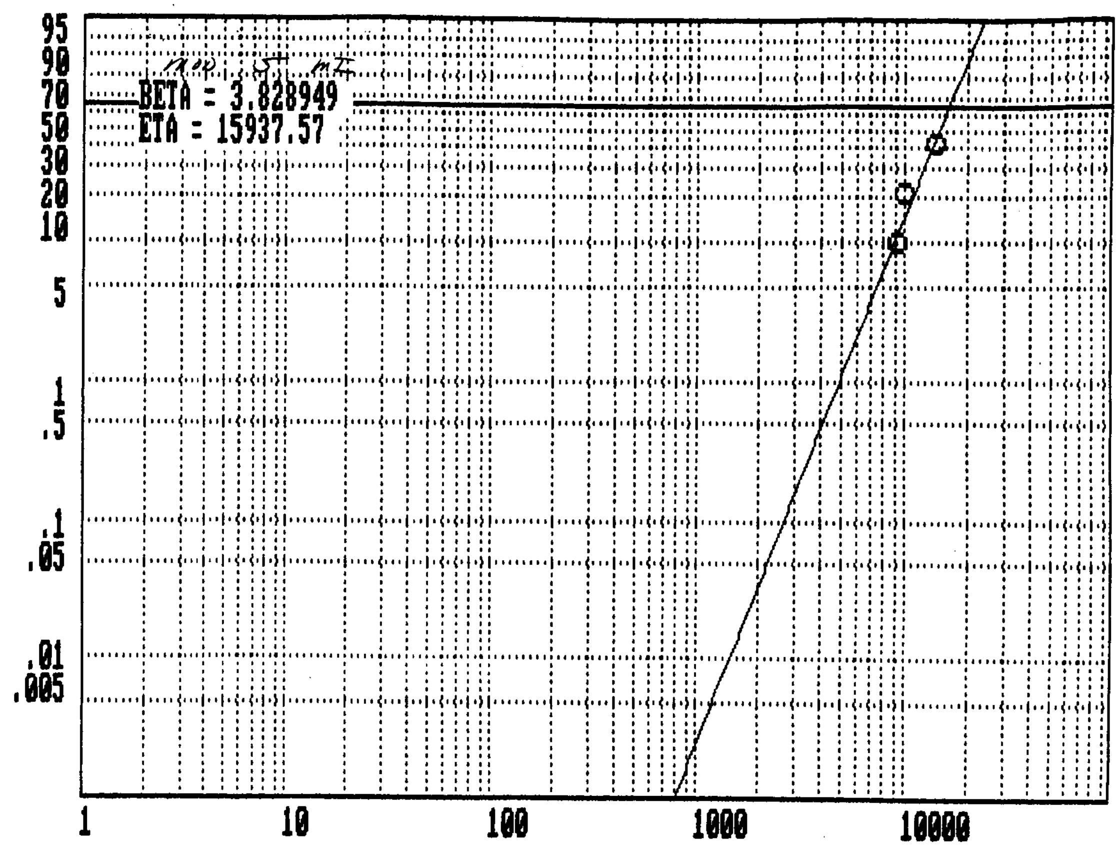
FAILURE CODES: 2,4 SUSPENSION CODE: NONE N = 11
MODEL 2, MI

FIGURE 7



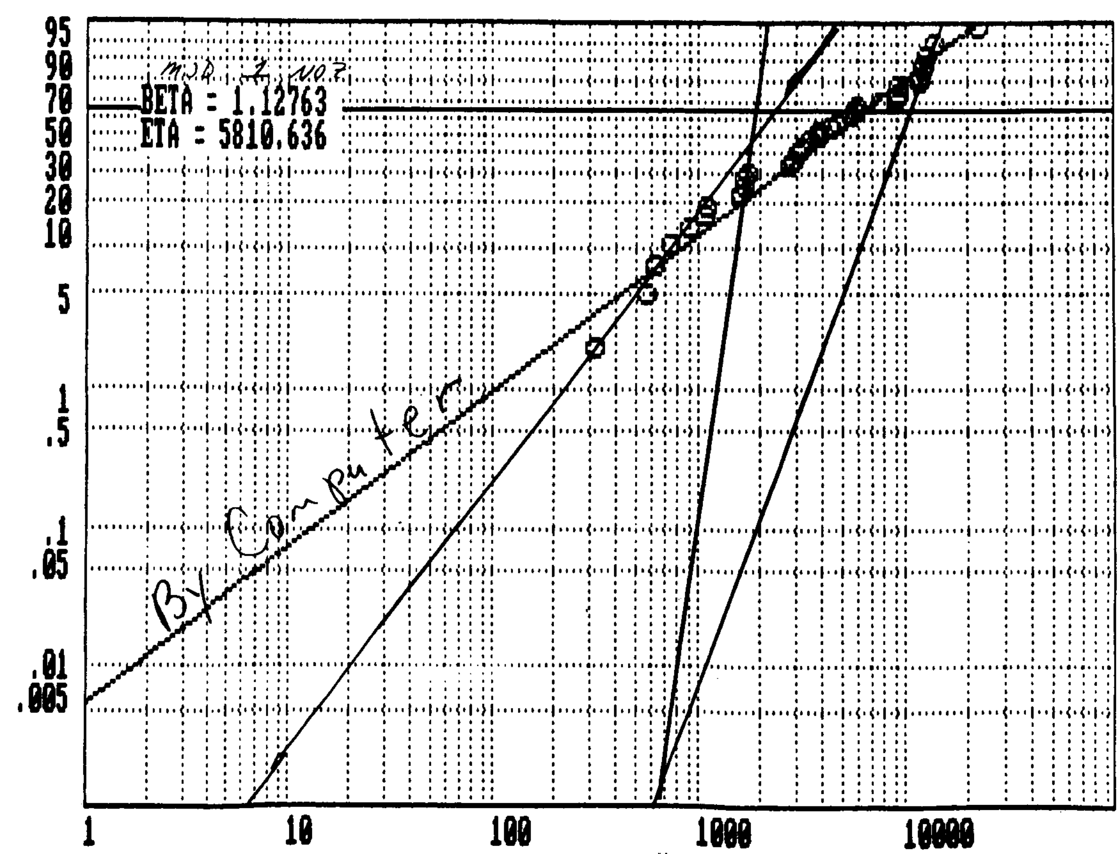
FAILURE CODES: 2,4,6 SUSPENSION CODE: 3 N = 26 Suspensions = 17
MODEL 4, MI

FIGURE 8



FAILURE CODES: 2,6 SUSPENSION CODES: 4,3 N = 26 SUSPENSIONS = 23

MODEL 5, MI FIGURE 9



FAILURE CODES: 2,3,4 SUSPENSION CODE: NONE N = 34

MODEL 1, NOZZLE FIGURE 10

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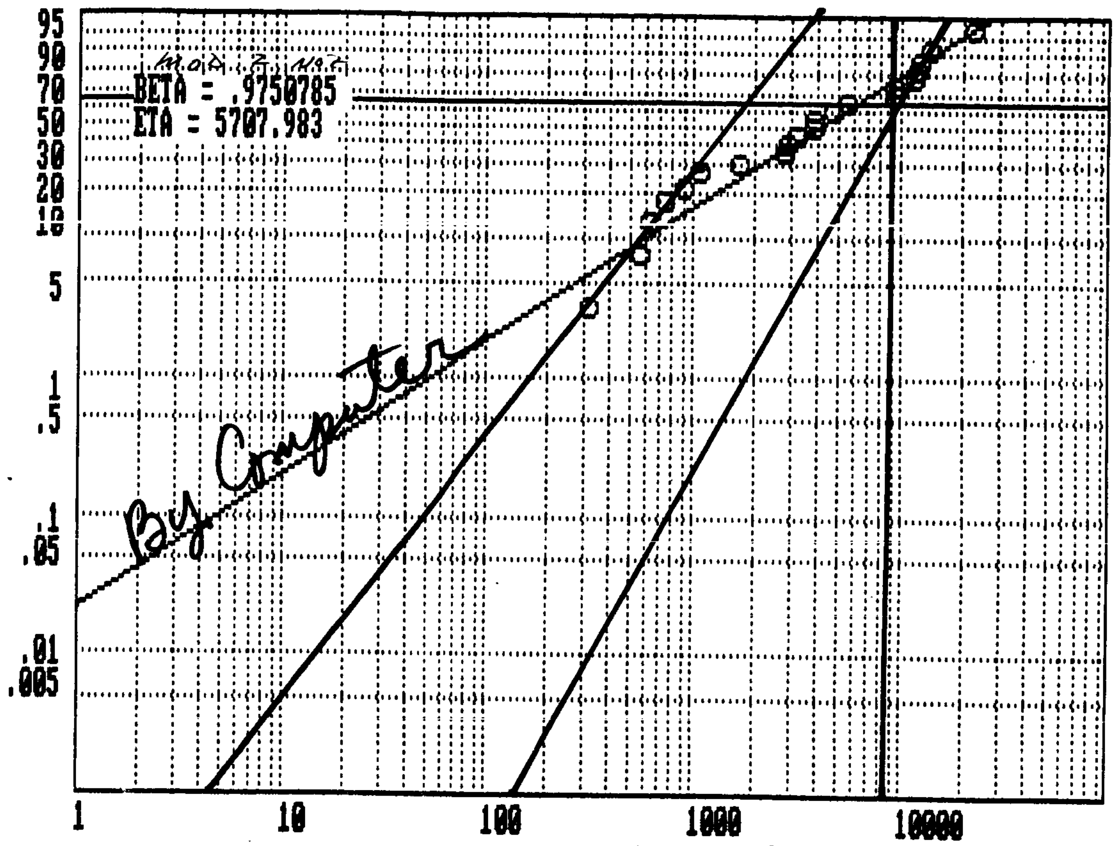
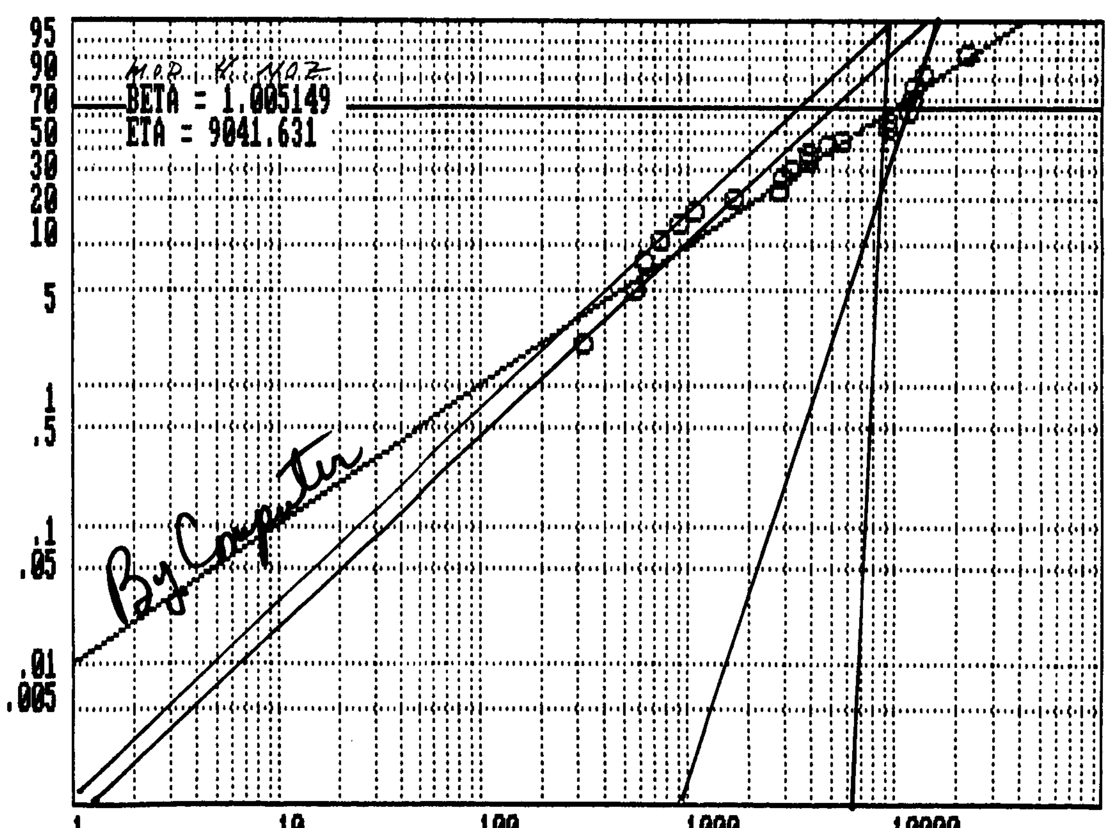
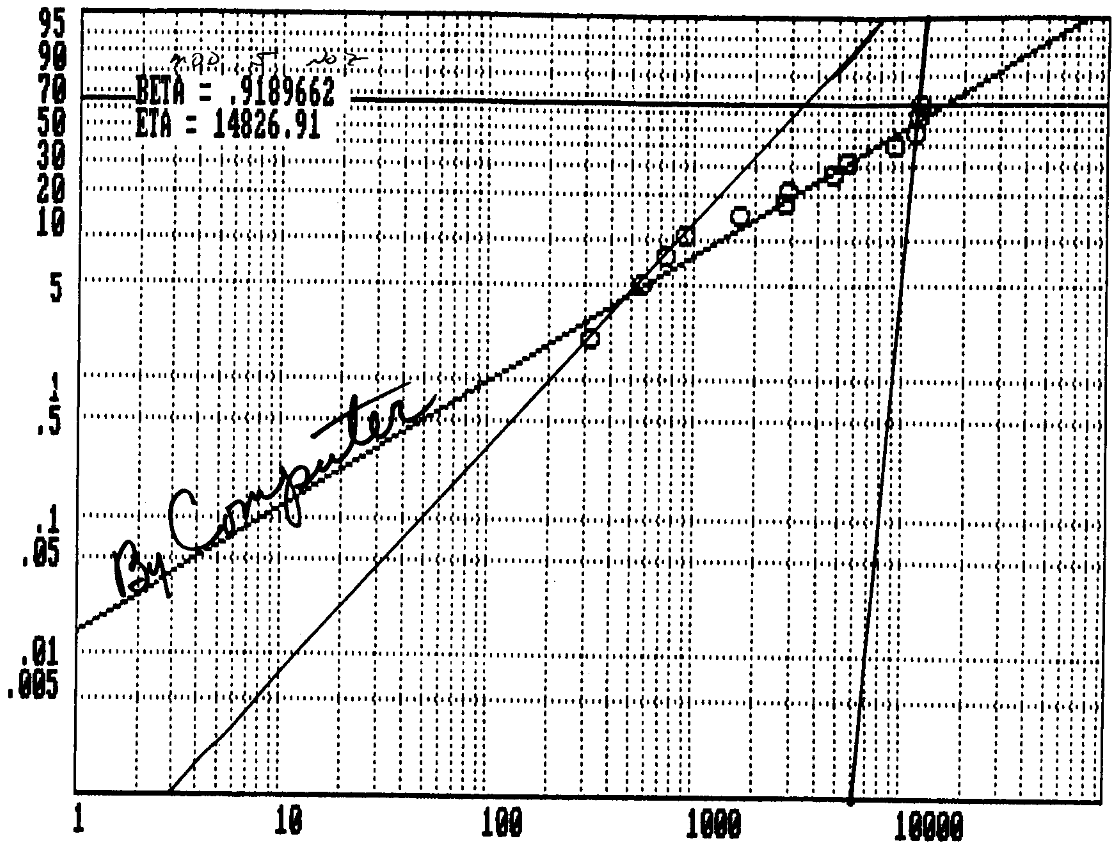


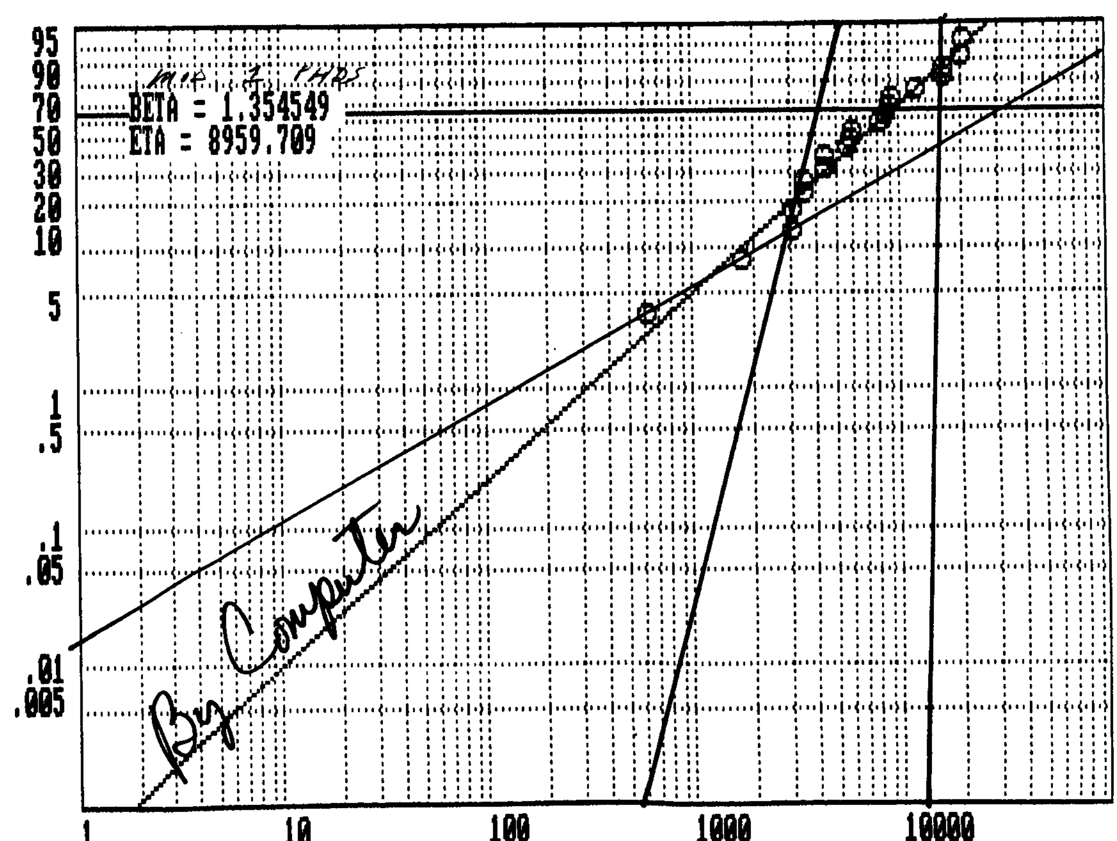
FAILURES CODES: 2,4 SUSPENSION CODE: NONE N = 21
MODEL 2, NOZZLE
FIGURE 11



FAILURE CODES: 2,4,6 SUSPENSION CODE: 3 N = 34 SUSPENSIONS = 13
Model 4, NOZZLE
FIGURE 12



FAILURE CODES: 2,6 SUSPENSION CODES: 4,3 N = 34 SUSPENSIONS = 21
MODEL 5, NOZZLE
FIGURE 13



FAILURE CODES: 2,3,4 SUSPENSIONS CODE: NONE N = 20
MODEL 1, POWERHEAD
FIGURE 14

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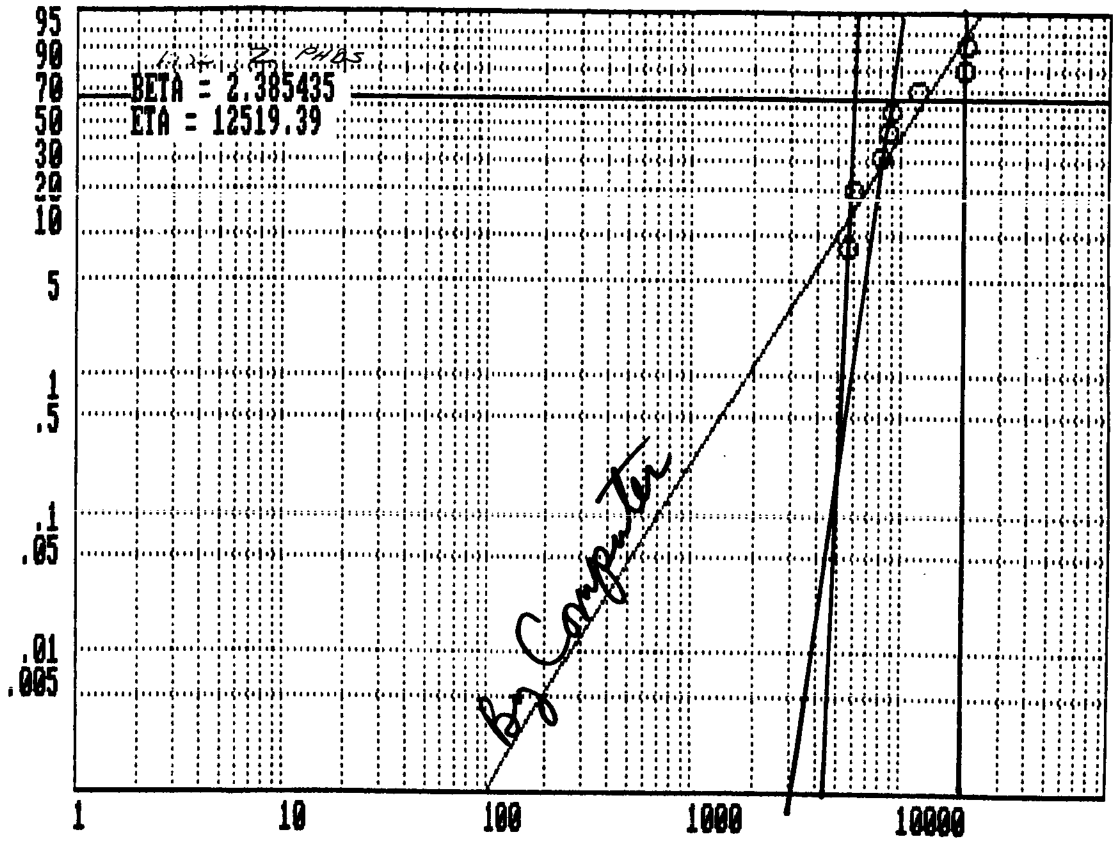
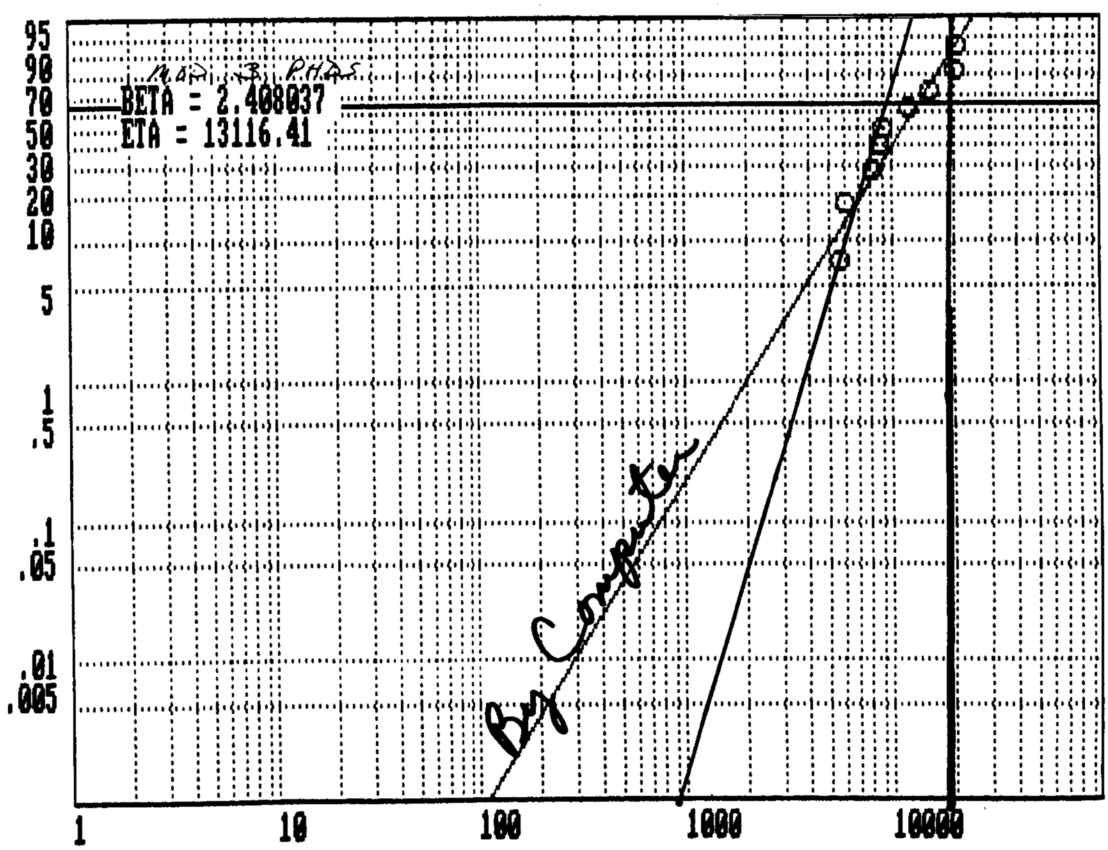


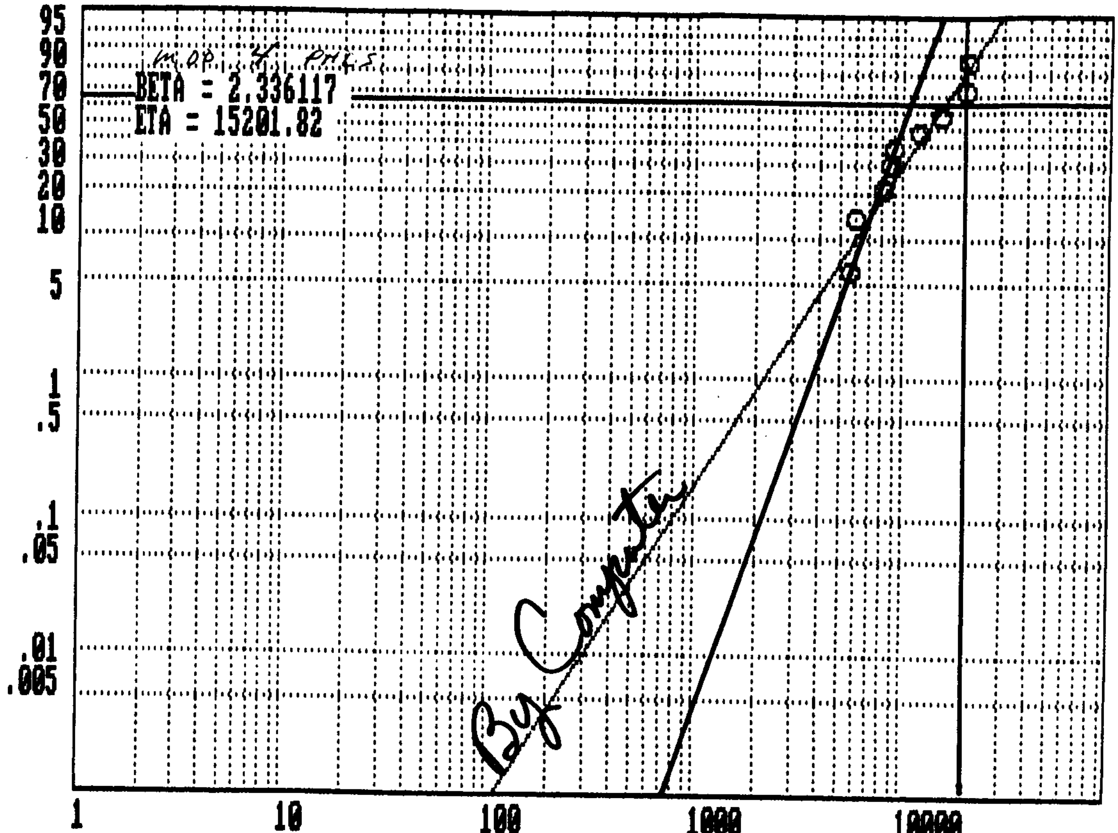
FAILURE CODES: 2,4
MODEL 2, POWERHEAD

SUSPENSION CODE: NONE N = 8
FIGURE 15



FAILURE CODES: 2,3,4
MODEL 3 , POWERHEAD

SUSPENSION CODES: NONE N = 9
FIGURE 16

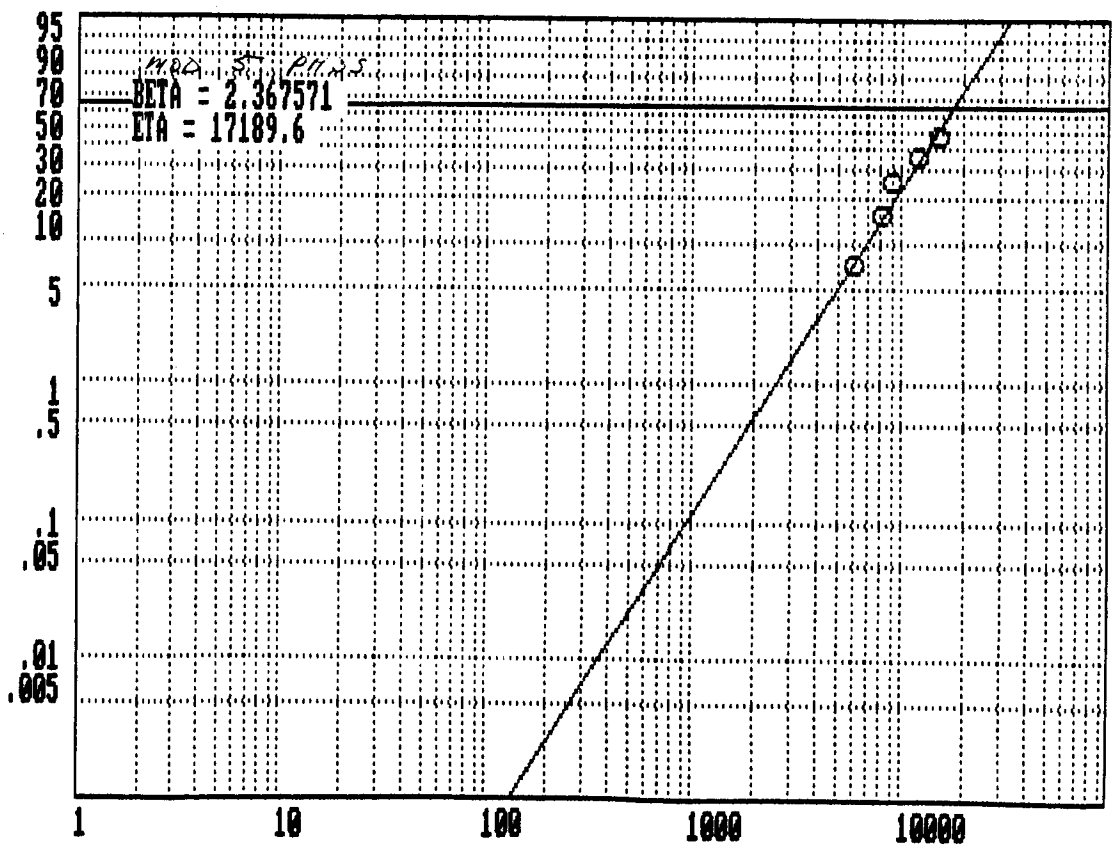


FAILURE CODES: 2,4,6
Model 4, POWERHEAD

SUSPENSION CODE: 3

N = 21 SUSPENSIONS = 12

FIGURE 17

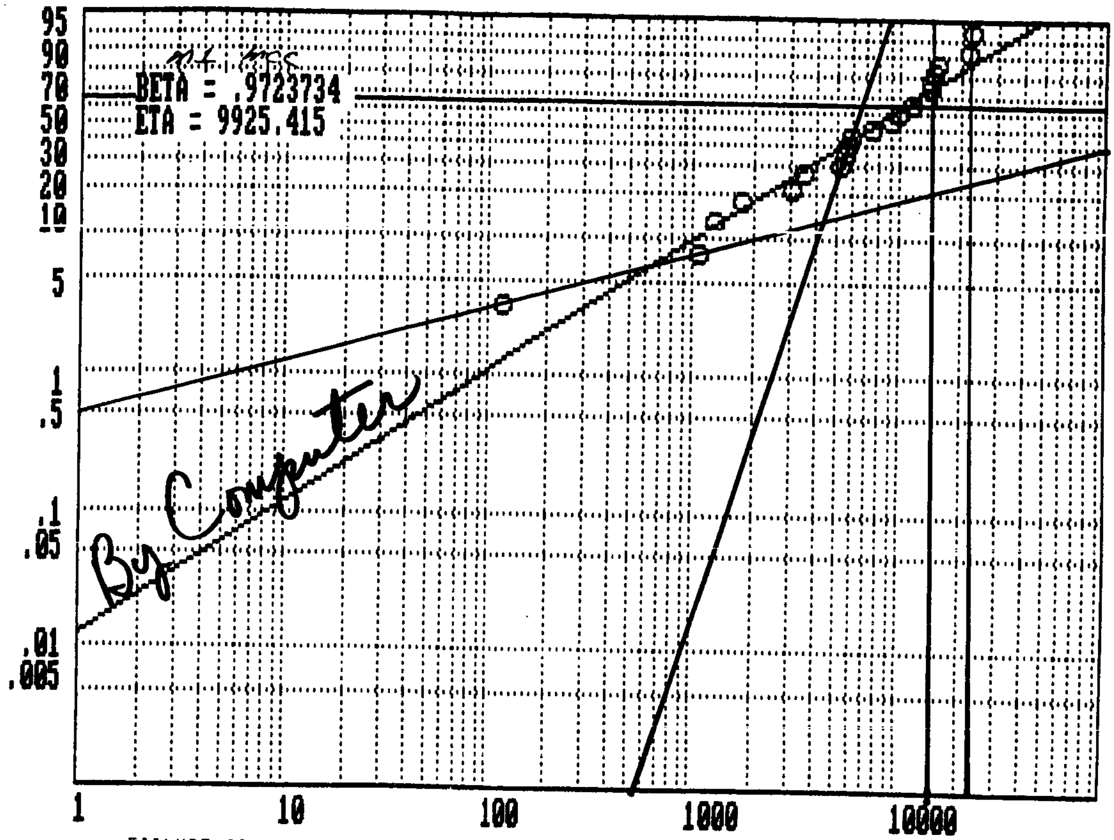


FAILURE CODES: 2,6
MODEL 5, POWERHEAD

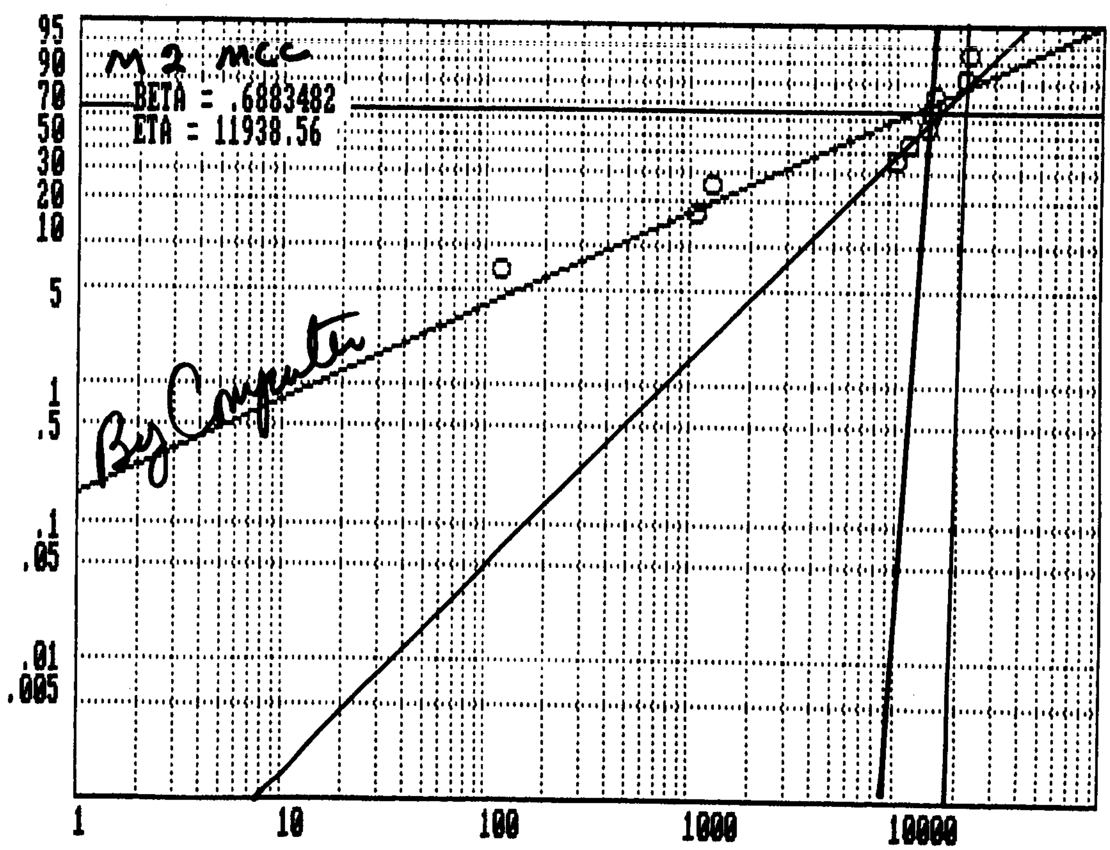
SUSPENSION CODES: 4,3

N=21 SUSPENSIONS = 16

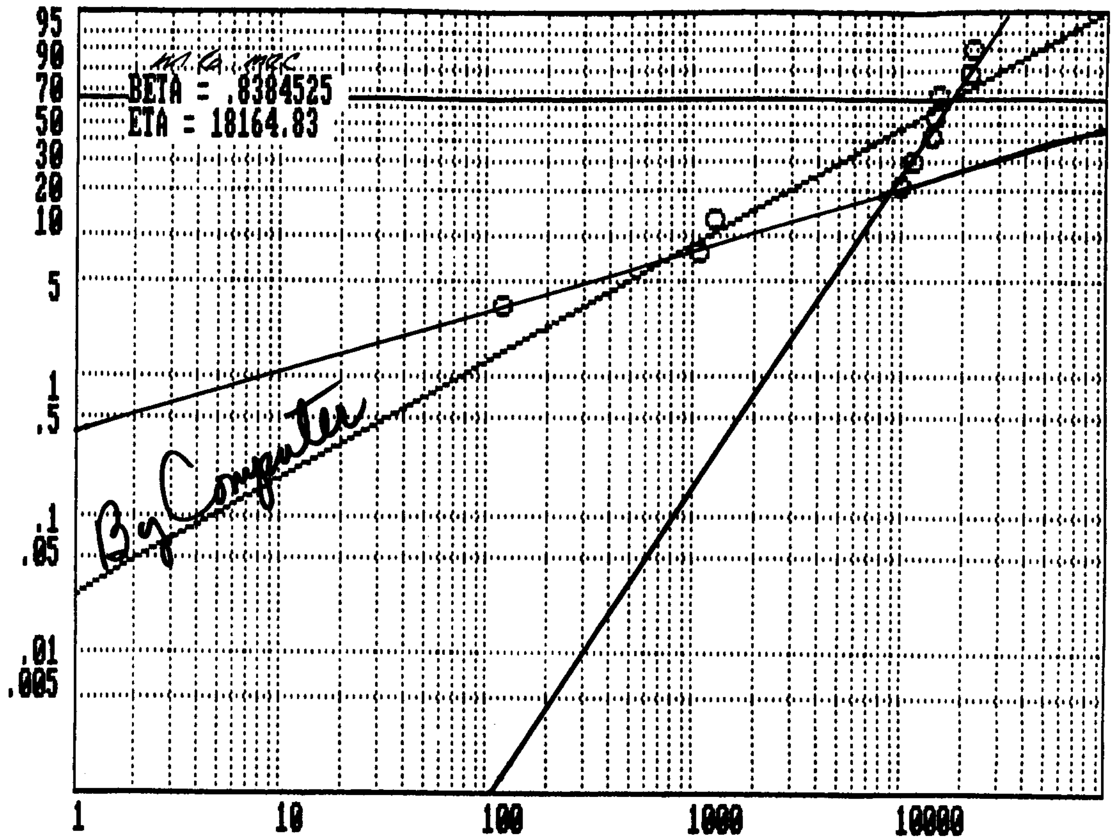
FIGURE 18



FAILURE CODES: 2,3,4 SUSPENSION CODE: NONE N = 21
MODEL 1, MAIN COMBUSTION CHAMBER FIGURE 19



FAILURE CODES: 2,4 SUSPENSION CODE: NONE N = 10
MODEL 2, MCC
FIGURE 20



FAILURE CODES: 2,4 SUSPENSION CODE: NONE N = 21 SUSPENSIONS = 11
MODEL 6, MCC

FIGURE 21

EP12525

ORGANIZATION: EP22	MARSHALL SPACE FLIGHT CENTER	NAME: LOU ALLEN GRAY
CHART NO. 19	STRATIFICATION OF SSME PARTS	DATE: AUGUST 8, 1986

SSME PARTS MANAGEMENT
DATA SHEET

MANUFACTURER: ____________

PART	CODE	SUBCODE	DATE	BATCH NO.

FIGURE 22

failure modes. For model 3 (see figure 16) the other visible failure modes are closer to expected life the results is similar to model 2. Model 4 has no extensive change in the number of failure modes (see figure 17). Model 5 (see figure 18) shows possibly some filtering process yet the results does not sufficiently represent real data.

Main Combustion Chambers (MCC)

Model 1 for the MCC reflects the generation of a multiple failure modes (see figure 19). Model 2 has most of the variance in betas as model 1 (see figure 20). Model 6 shows no alteration as far as fewer failure modes (see figure 21).

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The generation of betas within a small interval of 1 reflects what is happening to most SSME parts. For, the safety factors generate pseudo failure modes. The basis of the previously mentioned conjecture is that the cycle to complete failure is interrupted by a variety of procedures. These procedures are maintenance schedules, visual inspection, and a need for accessibility when maintaining other parts. For this study, the parts studied are basically classified as being in the same group. The models for the different part tended to generate similar multiple failure modes patterns. The constant failure rate reflects some consistency in maintenance management rather than parts behavior. Hence, the categories for failure must be assessed using some criteria as to what is to be examined. The computer program used for this study is blind to examining multiple failure modes or extreme points when graphing by ranking.

Recommendations

Due to the excessive amount of time it took to code failure modes, I am recommending that a very carefully though-out record keeping procedure be started (see figure 22). Any part removed from the SSME should be categorized immediately and the life management files should be augmented by computer. Design alterations should be clearly identified as being distinct from repair due to some problem. The removal of any part from service must be fully coded. Retirement reason should be spelled out as to whether it is due to the inability to perform the work of the original design or whether a new design is being used. For those parts where failure is not precisely defined, the engineers monitoring and studying the part should have a consistent agreement on procedures to help eliminate subjectivity. The sensitivity of new materials used for parts must be examined by looking at the mathematical behavior for: (1) stress versus temperature in various environments, (2) alternating stress versus cycles, (3) elongation pct versus temperature, (4) reduction of area part versus temperature, and (5) specific heat BTU/LB-F versus temperature. Factorial Experiments as in the book by Patrick O'Connor are needed to assist the engineer in deciding which factor contribute most to the failure modes reflected in the Weibull graphs.

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